LOG-IDEAH: ASP for Architectonic Asset Preservation

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Abstract

To preserve our cultural heritage, it is important to preserve our architectonic assets, comprising buildings, their decorations and the spaces they encompass. In some geographical areas, occasional natural disasters, specifically earthquakes, damage these cultural assets. Perpetuate is a European Union funded project aimed at establishing a methodology for the classification of the damage to these buildings, expressed as "collapse mechanisms". Structural engineering research has identified 17 different collapse mechanisms for masonry buildings damaged by earthquakes. Following established structural engineering practice, paper-based decisions trees have been specified to encode the recognition process for each of the various collapse mechanisms. In this paper, we report on how answer set programming has been applied to the construction of a machine-processable representation of these collapse mechanisms as an alternative for these decision-trees and their subsequent verification and application to building records from L'Aquila, Algiers and Rhodes. As a result, we advocate that structural engineers do not require the time-consuming and error-prone method of decisions trees, but can instead specify the properties of collapse mechanisms directly as an answer set program.

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1 Introduction

It is useful to be able to make a rapid and reliable assessment of the vulnerability of a building after a seismic shock, to determine (i) the stability of the building and hence the acceptable proximity of public access (ii) what immediate preservation actions are appropriate, and (iii) potential risks from subsequent seismic activity.

The Perpetuate project aims to combine two approaches in order to deliver assessments with a higher degree of confidence. The one on which we report here takes the form of an expert survey, based on an approach called LOG-IDEAH (LOGic trees for the Identification of Damage due to Earthquakes for Architectural Heritage) [10]. The complementary mechanical model-based approach is called FaMIVE (Failure Mechanism Identification and Vulnerability Evaluation) [2, 3, 4]. Both procedures are aimed at identifying the seismic

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behaviour of an architectonic asset on the basis of data collected by rapid survey or by photographic observation. The difference between the two methodologies is that LOG-IDEAH is an intuitive (human) logic procedure that relies on seismic damage collection for the identification of the failure modes of the architectonic assets, while FaMIVE is a numerical approach which uses geometric and mechanical (based on the properties of the building materials involved) data for the calculation of the performance of historical buildings.

The remainder of the paper is structured as follows: (i) we next (section 2) provide the context for the application, introduce the necessary domain terminology used in the rest of the paper and explain the hierarchical approach to the identification of individual building elements that forms the basis for the constructive procedure for the recognition of collapse mechanisms (ii) we then set out (section 3) how this damage and asset data is used to determine the possible collapse mechanisms; we start from the traditional structural engineering method of decision trees; this is followed by a much easier, declarative and computational approach of representing the building data and requirements for the individual collapse mechanisms as an answer set program (iii) in section 4 we briefly describe the data capture mechanism used to acquire the data to be used by the analysis, and (iv) in section 5 review the process and outline plans for future development.

2 Architectonic Asset Analysis

LOG-IDEAH depends upon an hierarchical approach, in which the architectonic asset is deconstructed into façades, the façades into structural elements and the structural elements into artistic assets. On the basis of this hierarchical approach, a logical methodology for the acquisition of the data has been developed in order to collect seismic damage data on site or by photographic observation.

Data collection for LOG-IDEAH entails the recording of information related to the damage position, damage type and damage level, that are observed at the level of the structural elements and artistic assets of the architectonic asset under inspection.

The collected data is then interpreted by means of logic trees that represent the knowledge and expertise of structural engineers, as they would use it for the identification of the global behaviour of an architectonic asset, and to recognise the failure modes of the architectonic asset in question.

2.1 Ontology

As with all disciplines, a comprehensive ontology[1] has been developed to capture and precisely define domain concepts and their relationships. Because the description of the analysis process is necessarily expressed in terms of this ontology, we give a brief overview of the elements required for reading the remainder of this paper. A formal representation in OWL has been developed, but that is not the subject of this paper and is not used directly in what follows. There are four top-level concept classes:

Architectonic asset (AA): This covers seven classes of buildings (A, ..., G) from mansions, through mosques, aqueducts, city walls and obelisks to historical centres (such as L'Aquila, in which the case-study building treated here is located).

[1] While using the word ontology we are not referring to semantic annotation in terms of an XML description, but an establied set of related concepts in the field of structural engineering

Macro-element (ME): This is a set of abstract concepts, used to group structural elements, comprising four classes: vertical, horizontal, vaulted and staircases.

Structural element (SE): This comprises four groups, corresponding to the MEs above, of concrete classes such as piers and spandrels (vertical), rafters and tie-beams (horizontal), buttresses and bosses (vaulted) and cantilever and steps (staircases).

Artistic asset (AA): This is a set of three groups of three abstract classes, used to categorize the various forms of decoration that may be attached to a structural element. Fresco's, friezes are just two examples of artistic assests.

2.2 Localisation and Identification of Damage

The essence of the the survey approach is to construct a rectilinear map of each façade, based on the structural elements (SE) of which it is composed, label each SE by type (pier, pillar, spandrel, arch) and associate with it the kind of damage (vertical crack, horizontal crack, diagonal crack) and the degree of damage (light, severe, near collapse, collapsed). This data then forms the input to the encoding of the structural engineer's decision tree that identifies the collapse mechanism.

The zone under consideration (and the buildings within it) may be thought of as a n-ary tree, rooted at the zone identifier, with whichever district the building is located, whose leaves are, in the extreme, the artistic assets, such as a carving or a balcony, that decorate the building and the interior nodes are everything in between.

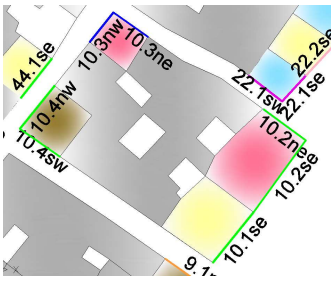
The ultimate objective, from an engineering perspective, is to establish a relationship between each artistic asset and the façade to which it is attached, since this is how it may be damaged if the façade is subject to a collapse mechanism. This is achieved by defining a hierarchical naming scheme. The method starts by dividing the urban map into blocks and enumerating the blocks and the buildings located therein. Thus, the name associated with a particular asset is given by (block number + building number), followed by the façade orientation. The final suffix is the number of the region (in a rectilinear map) of the façade plus a letter that refers to the type of topological relationship between the asset and the façade. For example (see Figure 1), in the map of the historical centre of L'Aquila – damaged by an earthquake in 2009 – the building highlighted in red is named 10.4, since this building is the fourth building of the block number 10. Furthermore, a sequence of façades is associated with this building, describing those which have been inspected, namely 10.4sw and 10.4nw, while those on the remaining sides are still to be inspected.

The relationship between façades and the structural elements is established after identifying vertical (piers/pillars/columns) and horizontal (spandrels/arches) structural elements of the façade, as shown in Figure 1. Each structural element is labelled by a pair of positive integers, where the first is the number of the floor, encoding the horizontal alignment of the elements and the second is the position of the element, encoding the vertical alignment. Thus, looking at Building 10.4 (Figure 1d) and façade 10.4sw, the identification of its structural elements is clear.

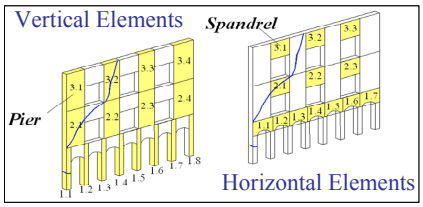
Once these relationships have been established, seismic damage information at the level of SEs is collected, then interpreted, first at the level of MEs (for example, façade) and then at the level of AA (building).

The damage type classification is given by: (i) H, denoting a horizontal crack (ii) V, a vertical crack (iii) D1, a diagonal crack from upper right to bottom left (iv) D2, a diagonal crack from upper left to bottom right (v) X, being the occurrence of D1 and D2 in the same structural element (vi) Sp, denoting spalling, which indicates surface fragmentation of the (building) material, and (vii) Cr, denoting crushing, which indicates interior fragmentation.

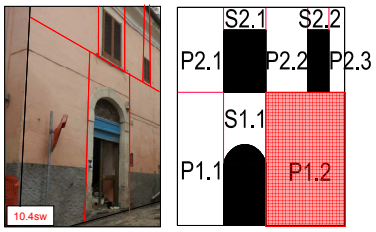
(a) The division of L'Aquila into districts



(b) Identification of the façades on individual buildigs in district 10



(c) The structural enumeration convention



(d) Facade sw of building 10.4 is broken into structural elements to enable reference to pier 2 on floor 1

Figure 1 The division of L'Aquila into districts, façade identification on individual buildings in district 10, the structural enumeration convention and the referencing of pier 2 on floor 1.

The damage level severity classification is given by: (i) LD: light damage (ii) SD: severe damage (iii) NC: near collapse, and (iv) C: collapsed.

All of the above is carried over directly into the ASP encoding (see Figure 4).

3 Representation and Reasoning

3.1 Decision Trees

One of the primary deliverables of the Perpetuate project is a process for determining the various collapse mechanisms for earthquake-damaged masonry buildings, by examining the damage to the structural elements and the artistic assets of the building. So far, the architects have identified 19 distinct such mechanisms, each of which is depicted in Figure 2.

The original (manual) method developed for identifying the collapse mechanism uses the traditional structural engineering approach of decision trees. Figure 3 shows the decision tree for collapse mechanism A. This mechanism occurs when there are vertical cracks on either side of a façade starting from the top floor. The graphics on the right highlight on which floor the decision tree is operating at a given time.

Such a manual approach, which also requires specialized knowledge on the part of the observer, is not very efficient at scale for dealing with an earthquake zone where several hundreds of buildings are damaged, like for example the sites involved in the Perpetuate Project: L'Aquila and the Casbah of Algiers. This led to the requirement for a computational mechanism to support the survey process by non-experts. Given the intrinsically procedural nature of decision trees, a procedural programming approach could have been chosen. However, given the declarative description of the collapse mechanisms (e.g. vertical

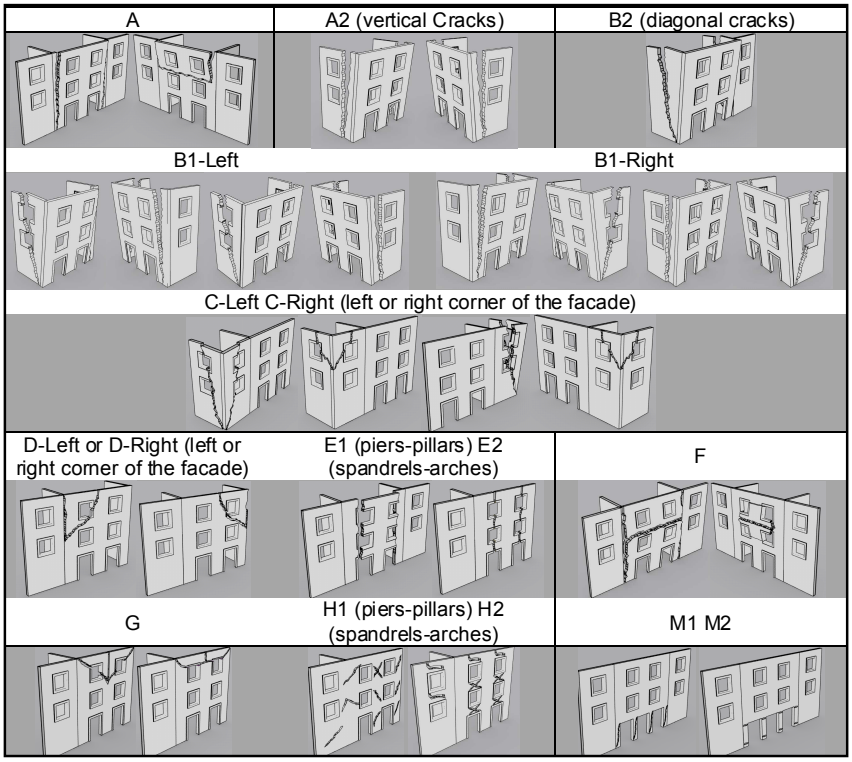


Figure 2 Illustration of the variety of collapse mechanisms.

cracks on either side of a façade) provided by the architects on the project, we believed the declarative paradigm would be more suitable. In addition to providing a computational model, it also allowed us to verify and validate the decision trees provided by the arhcitects. We have chosen to implement the collapse mechanism inference procedure and the description of the buildings using answer set programming[8, 9] with *AnsProlog* as the implementation language[1].

3.2 Answer Set Programming

Answer-set programming (ASP) [8] is a declarative programming paradigm in which a logic program is used to describe the requirements that must be fulfilled by the solutions of a certain problem. The solutions of the problem can be obtained through the interpretation of the answer sets of the program, usually defined through a variant or extension of the stable-model semantics [8].

In this paper we use *AnsProlog* as our implementation language. Its basis component are atoms, elements that can be either true or false. An atom a can be negated using *negation as failure*. A *literal* is an atom a or a negated atom *not* a. We say that *not* a is true if we cannot find evidence supporting the truth of a. Using atoms and literals as building blocks we can create rules. In their general form they are represented as:

$$\mathtt{a} :- \mathtt{b}_1, \ldots, \mathtt{b}_m, \mathtt{not}\ \mathtt{c}_1, \ldots, \mathtt{not}\ \mathtt{c}_n.$$

where a, b_i, and c_j are atoms. Intuitively, this can be read as: *if all atoms* b_i *are known/true and no atom* c_i *is known/true, then* a *must be known/true.*

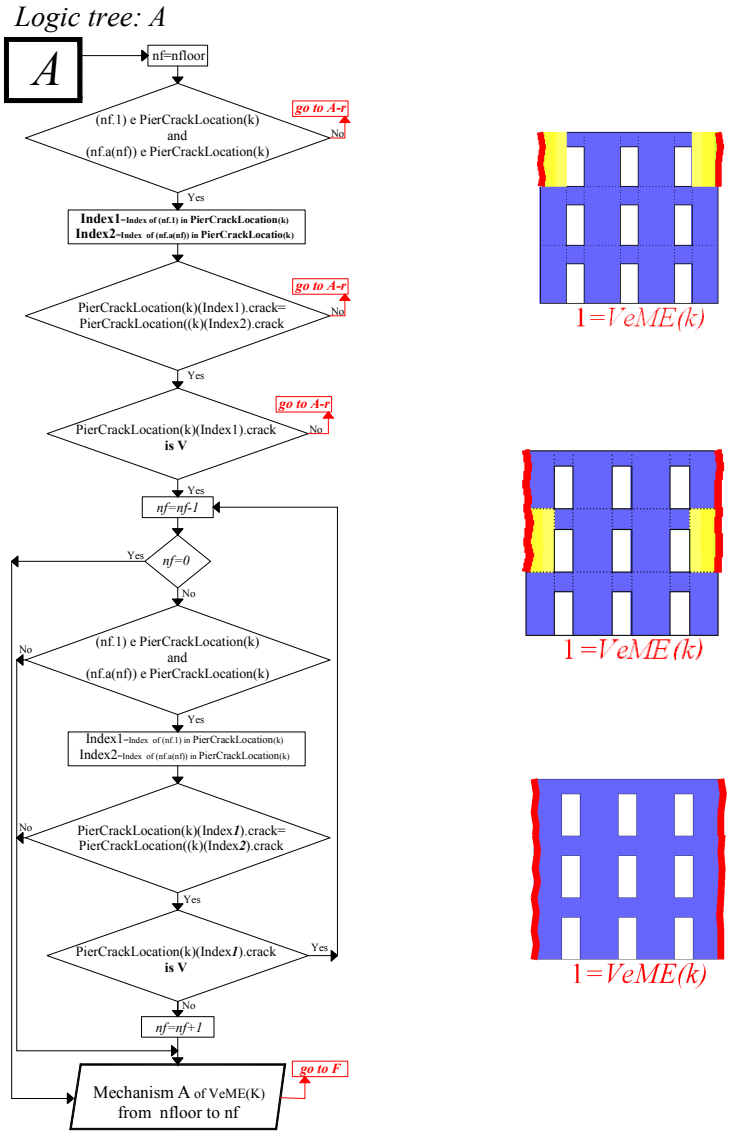


Figure 3 The logic tree for mechanism A (left) and sketches (right).

We refer to a as the head and $b_1, \ldots, b_m, not\ c_1, \ldots, not\ c_n$ as the body of the rule. Rules with empty bodies are called *facts*. Rules with empty heads are referred to as *constraints*, indicating that no solution should be able to satisfy the body. A *program* is a set of rules. The semantics is defined in terms of *answer sets*, i.e. assignments of true and false to all atoms in the program that satisfy the rules in a minimal and consistent fashion, taking into account that the truth of an atom cannot be based on the absence of proof (i.e. the truth of an atom cannot indirectly be inferred by its own negation). A program has zero or more answer sets, each corresponding to a solution.

Algorithms and implementations for obtaining answer sets of logic programs are referred to as *answer-set solvers*. The most popular and widely used solvers are DLV [6], providing solver capabilities for disjunctive programs, and the SAT inspired CLASP [7].

```
% @block buildingconstants {
%       provides the constants used in damage description of buildings
% @atom damageType(T)
%       type of damage from vertical;horizontal;diagonal crack / ;
%       diagonal crack \ ;
%       x shape;spalling;crushing
% @atom damageLevel(L)
%       severity of damage from damage limitation;significant damage;
%       near collapse;collapse

damageType(v;h;d1;d2;x;s;cr).
damageLevel(ld;sd;nc;c).
```

Figure 4 The facts describing the damage types and levels of buildings.

3.3 *AnsProlog* for Collapse Mechanisms

Instead of using the procedural decision-trees as our starting point, we used the sketches of the collapse mechanisms together with a discussion with a domain expert as our starting point. Since the answer set program will be integrated with web-interface (see next section) that collects data for each building individually, our answer set program only needs to consider the representation of a single building at any given time.

To start the modelling process, it was necessary to decide upon the representation of the various structural elements of the building. With the objective of making the logic accessible to the architects, we annotated all our program fragments with a description of the atoms used. To do so, we used a subset of the annotation language LANA[5]. This language uses program comments plus semantic tags in the style of Javadoc t o describe the various components of the program. We only used the `@block` tag, indicating a collection of rules, and the `@atom` tag to describe individual atoms and their terms.

We first defined facts to denote the various damage types and damage levels. The encoding is shown in Figure 4.

This was followed with facts for the description of the structural elements themselves. The ultimate goal is that this information is automatically generated on the basis of information gathered by non-expert surveyors on site (see next section for more information on the data collection). For some of the collapse mechanisms, numerical information is required, such as the number of piers with a vertical crack or the percentage of piers that are damaged. Since this data can be generated during the data collection process, we choose to incorporate it as facts rather than compute it in the answer set program.

Figure 5 contains the description of a synthetic building with one visible façade which exhibits an out-of-plane collapse mechanism of type A.

Having the description of the building, the different collapse mechanisms can be encoded. Rather than using the rather procedural decision trees as a starting point, the encoding is derived solely from the schematic pictures (see right-hand side of Figure 5 for an example). Each collapse mechanism is encoded in a separate file and LANA block for ease of testing, flexibility and readability.

In this paper we illustrate this process with the intra-façade collapse mechanism A. To demonstrate the ease of use of the ASP-encoding, we subsequently extend this to the inter-façade mechanism A2.

Figure 6 shows the block of *AnsProlog* code that allows us to detect collapse mechanism A. Most encodings of collapse mechanisms, and mechanism A is not an exception, start from the top floor of a façade and try to identify a certain crack pattern. If found, lower floors are tested until a floor is found which does not have this desired pattern. The system will then return the specific pattern with the range of floors involved in the pattern. For the

```
%This code is automatically generated from the
% xml data gathered through the web-site
%
facade(1..1).
floorNumber(1,1..3).

pierCrack(1,3,1,v,sd).
pierCrack(1,3,4,v,sd).
piersFloorNumber(1,3,1..4).
spandrelFloorNumber(1,3,1..3).

pierCrack(1,2,1,v,sd).
pierCrack(1,2,4,v,sd).
piersFloorNumber(1,2,1..4).
spandrelFloorNumber(1,2,1..3).

pierCrack(1,1,1,v,sd).
pierCrack(1,1,4,v,sd).
piersFloorNumber(1,1,1..4).
spandrelFloorNumber(1,1,1..3).

numberOfPiers(1,12).
percent75Piers(1,9).
numberOfSpandrels(1,9).
percent75Spandrels(1,7).

pierVCracks(1,6).
pierHCracks(1,0).
pierD1Cracks(1,0).
pierD2Cracks(1,0).
pierXCracks(1,0).

spandrelVCracks(1,0).
spandrelHCracks(1,0).
spandrelD1Cracks(1,0).
spandrelD2Cracks(1,0).
spandrelXCracks(1,0).
```

A simple building with just one facade and three floors

Crack data for floor level 3: vertical cracks in the first and last piers, with severe damage

Crack data for floor level 2: vertical cracks in the first and last piers, with severe damage

Crack data for floor level 1: vertical cracks in the first and last piers, with severe damage

This block computes the number of elements that constitute 75% of each kind. This data is used to identify collapse mechanisms H1 and H2

This block summarizes pier crack data for facade 1: in this case there are 6 vertical cracks

This block summarizes spandrel crack data for facade 1: in this case there are no cracks

Figure 5 The encoding of a single façade exhibiting collapse mechanism A (out of plane).

```
% LANA comments omitted for spacial reasons

patternAl(Fa,Fl) :-
   pierCrack(Fa,Fl,1,v,Ll),topFloor(Fa,Fl),
   floorNumber(Fa,Fl), facade(Fa),damageLevel(Ll).
patternAr(Fa,Fl) :- rightPierFloor(Fa,Fl,R),
   pierCrack(Fa,Fl,R,v,L2),topFloor(Fa,Fl),
   facade(Fa), floorNumber(Fa,Fl), damageLevel(L2).

patternAl(Fa,Fl) :-
   pierCrack(Fa,Fl,1,v,Ll), floorNumber(Fa,FlH),floorNumber(Fa,Fl),
   patternAl(Fa,FlH), Fl = FlH - 1, facade(Fa),damageLevel(Ll).
patternAr(Fa,lL) :-
   pierCrack(Fa,Fl,R,v,L2), rightPierFloor(Fa,Fl,R),
   floorNumber(Fa,FlH),floorNumber(Fa,Fl), ,damageLevel(L2)
   patternAr(Fa,FlH), Fl = FlH - 1, facade(Fa).

lowpatternAl(Fa,Fl) :-
   patternAl(Fa,Fl), not patternAl(Fa,Fll), Fl = Fll + 1,
   floorNumber(Fa,Fl),floorNumber(Fa,Fll), facade(Fa).
lowpatternAr(Fa,Fl) :-
   patternAr(Fa,Fl), not patternAr(Fa,Fll), Fl = Fll + 1,
   floorNumber(Fa,Fl),floorNumber(Fa,Fll), facade(Fa).

lowpatternAl(Fa,1) :- patternAl(Fa,1).
lowpatternAr(Fa,1) :- patternAr(Fa,1).

lowpatternA(Fa) :-
   lowpatternAl(Fa,Fl), lowpatternAr(Fa,Fll), facade(Fa),
   floorNumber(Fa,Fl), floorNumber(Fa,Fll).


collapseMechanism(outOfPlaneAt(Fa,FlT,Fr),patternA) :-
   lowpatternAl(Fa,Fl), lowpatternAr(Fa,Fr), Fl < Fr, topFloor(Fa,FlT),
   floorNumber(Fa,Fl), floorNumber(Fa,Flt), facade(Fa).
collapseMechanism(outOfPlaneAt(Fa,FlT,Fl),patternA) :-
   lowpatternAl(Fa,Fl), lowpatternAr(Fa,Fr), Fl >= Fr, topFloor(Fa,FlT),
   floorNumber(Fa,Fl), floorNumber(Fa,Flt), facade(Fa).
```

This rule determines whether the top leftmost pier/ top rightmost has a vertical crack. Partial crack patterns to stimulate reuse

For a given floor, if a leftmost/rightmost vertical crack pattern was determined on the floor above, check if this also so for the current floor

This rule determines the lowest floor on which a left-/right vertical crack was determined

Starting position to check for finding the lowest floor with continuous vertical cracks on the left/right

This rule establishes that both left and right side have a vertical cracks. Is used the exclude other collapse mechanisms

Indicates when a collapse mechanism of PatternA occurs from the top of the facade to the floor where there is vertical crack on both sides

Figure 6 The rules used to recognise collapse mechanism A.

encoding, distinct parts of a sought crack pattern are tested separately (e.g. `patternAr` and `patternAl`) to support reuse for other mechanism using the same partial patterns. For each partial pattern, the lowest floor (e.g. `lowpatternAl`(`Fa`, `Fl`) and `lowpatternAr`(`Fa`, `Fl`)) where the partial patterns occurs, is determined to be combined to form the collapse mechanism (e.g. `collapseMechanism`(`outOfPlaneAt`(`Fa`, `FlT`, `Fr`), `patternAa`)).

The scenario described here in detail is one relatively simple type of collapse mechanism where, there are vertical cracks down both sides within a façade, leading to the collapse of the entire front of the building. Most collapse mechanisms are intra-façade, but there

```
% LANA comments omitted for spacial reasons.

lowpatternAa(Fa) :-
   lowpatternAl(FaR,Fl), lowpatternAr(FaL,Fll),
   floorNumber(FaR,Fl),floorNumber(FaL,Fll),
   rightFacade(Fa,FaR),leftFacade(Fa,FaL),facade(Fa;FaR;FaL).

collapseMechanism(
      outOfPlanePortion(Fa,FlT,Fll),
      patternAb) :-
   lowpatternAl(FaR,Fl), lowpatternAr(FaL,Fll),Fl<Fll,
   floorNumber(FaR,Fl),floorNumber(FaL,Fll),
   floorNumber(FaL,FlT),
   rightFacade(Fa,FaR),leftFacade(Fa,FaL),facade(Fa;FaR;FaL).

collapseMechanism(
      outOfPlanePortion(Fa,FlT,Fl),
      patternA2) :-
   lowpatternAl(FaR,Fl), lowpatternAr(FaL,Fll),Fll<=Fl,
   floorNumber(FaR,Fl),floorNumber(FaL,Fll),
   floorNumber(FaL,FlT),
   rightFacade(Fa,FaR),leftFacade(Fa,FaL),facade(Fa;FaR;FaL).
```

Uses atoms derived in scenarioA

Uses atoms derived in scenarioA

Figure 7 The A2 detection rules.

is a more complicated class of inter-façade mechanisms, such as illustrated by mechanism A2 (Figure mechanisms). This has much in common with mechanism A, in that there are vertical cracks on either side of the façade concerned, but those cracks are in the *adjacent* façades, and in consequence, the reasoning process must be applied not at the macro-element level, but across the architectonic asset as a whole. The relative ease with which is it possible to extend the analysis illustrates the benefit of the hierarchical approach to the representation of the building and the declarative nature of the encoding. In the encoding (Figure 7), we use reuse the partial patterns for vertical cracks on the left and right side of a façade, something which is not possible in the decision trees.

With all the 19 collapse mechanisms implemented, we can pass the building description, the encodings of each mechanism and some auxiliary files for computing, for example, the rightmost pier of a floor or the top floor of a façade, and for showing only the `collapsemechanism/2` to the answer set solver CLINGO[7] to determine which mechanism(s) are found for this building. Applying this to our synthetic Mechanism A Building, as encoded in Figure 5, the result is the identification of an out-of-plane collapse across three floors, as expected.

The verification process was approached by the creation of unit test cases for each of the 19 collapse mechanisms. While initially created manually, they were later re-created through the web-site described in the next section. Determining the collapse mechanisms for an entire building takes at most 1 or 2 seconds, which is signicantly faster than experienced human can manually go through the 19 decision trees.

4 Data Capture

The record of the collected seismic data has been facilitated by the use of a web-site[2] which permits expert and non-expert users to: (i) create of new architectonic asset records, effectively from anywhere (ii) draw simplified sketches of inspected façades (iii) record damage type and damage level to structural elements and artistic assets, (iv) upload photographic records of assets and asset damage, and (v) assess probable collapse mechanisms using the reasoning process described in the previous section.

Surveys are in progress and at this stage have collected records from buildings in L'Aquila and the Casbah in Algiers. Information regarding the buildings and their structural elements is stored in XML format, which can be converted to *AnsProlog* code, like in Figure 5. Integration between the Perpetuate web-site and LOG-IDEAH is currently in progress.

[2] `http://perpetuate.cs.bath.ac.uk/`

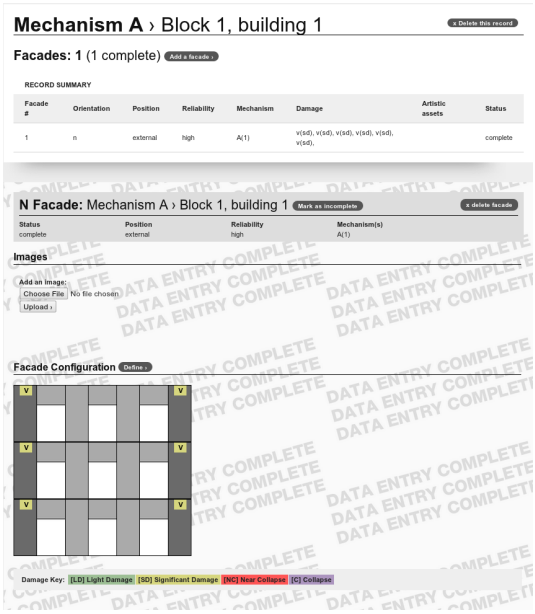


Figure 8 Extract from completed data entry in web browser.

5 Discussion and Future Work

In this paper, we introduced a computational representation and an alternative approach to the established structural engineering methodology of decision trees, which we believe is more efficient, flexible, intuitive and less error-prone. In the process of writing the answer set programs, a number of subtle errors were uncovered in the decision trees, as well as some oversights and shortcomings of building's representation, that would have been hard to find using the traditional pen-and-paper verification technique or a procedural implementation of the decision trees. Encoding the collapse mechanisms took us only a few days, including the time to get aquinted with the domain ontology. We hope in the future to apply a similar approach to other problem for which structural engineers use decision trees. By doing so, we hope to demonstrate ASP might be a good alternative to decision trees.

At the moment buildings are assumed to be relative regular for the purpose of continuous cracks. Piers and spandrels on different floors have similar size, lined-up are consecutive. The next version of the model and software will relax this constraint by using (structural) element as the basic component of a building rather pier or spandrel. In this way, wider piers can conceptually be encoded as three elements of type pier to allow for elements on several floors to be lined up.

The Perpetuate project is attracting attention from conservationists from across the world who would also like to enter building information into the repository. This will provide more data for architects to identify and specify more collapse mechanisms and to extend the approach to other types of buildings, such as stone, wood or earth.

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References

1 Chitta Baral. *Knowledge Representation, Reasoning, and Declarative Problem Solving*. Cambridge University Press, Cambridge, England, 2003.

2 D D'Ayala and E Speranza. Definition of collapse mechanisms and seismic vulnerability of historic masonry buildings. *Earthquake Spectra*, 19:479—509, August 2003.

3 D. F. D'Ayala. Force and displacement based vulnerability assessment for traditional buildings. *Bulletin Of Earthquake Engineering*, 3:235—265, December 2005.

4 Dina D'Ayala and Sara Paganoni. Assessment and analysis of damage in l'aquila historic city centre after 6th april 2009. *Bulletin of Earthquake Engineering*, 9:81–104, 2011. 10.1007/s10518-010-9224-4.

5 Marina De Vos, Doga Kiza, Johannes Oetsch, Jörg Pührer, and Hans Tompits. Annotating answer-set programs in lana. *Theory and Practice of Logic Programming*, 2012.

6 Thomas Eiter, Nicola Leone, Cristinel Mateis, Gerald Pfeifer, and Francesco Scarcello. The KR system dlv: Progress report, comparisons and benchmarks. In *Proceedings of the 6th International Conference on Principles of Knowledge Representation and Reasoning* (*KR 1998*), pages 406–417. Morgan Kaufmann, 1998.

7 M. Gebser, B. Kaufmann, A. Neumann, and T. Schaub. Conflict-driven answer set solving. In *Proceedings of the 20th International Joint Conference on Artificial Intelligence* (*IJCAI 2007*), pages 386–392. AAAI Press/The MIT Press, 2007.

8 Michael Gelfond and Vladimir Lifschitz. The stable model semantics for logic programming. In *Proceedings of the 5th International Conference and Symposium on Logic Programming*, pages 1070–1080. MIT Press, 1988.

9 Michael Gelfond and Vladimir Lifschitz. Classical negation in logic programs and disjunctive databases. *New Generation Computing*, 9(3-4):365–386, 1991.

10 Viviana Novelli and Dina D'Ayala. Seismic damage identification of cultural heritage assets. In *Seismic Protection of Curtural Heritage*, page 13, Antalya, Turkey, 2011.